Research Findings on Empirical Evaluation of Requirements Specifications Approaches

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Abstract

Numerous software requirements specification (SRS) approaches have been proposed in software engineering. However, there has been little empirical evaluation of the use of these approaches in specific contexts. This paper describes the results of a mapping study, a key instrument of the evidence-based paradigm, in an effort to understand what aspects of SRS are evaluated, in which context, and by using which research method. On the basis of 46 identified and categorized primary studies, we found that understandability is the most commonly evaluated aspect of SRS, experiments are the most commonly used research method, and the academic environment is where most empirical evaluation takes place.

Keywords: Software requirements specification, mapping study, empirical evaluation, empirical studies

1. Introduction

Software requirements specification (SRS) techniques have been developed for almost four decades. However, only recently has the requirements engineering (RE) community started actively investigating the practical usefulness of these techniques in specific project contexts [4][5][6]. Davis et al. focused on questions such as which elicitation technique is meaningful and in which situations.

The SRS is expressed in terms of one or more models. In contrast to models developed during the elicitation phase, late-phase requirements models tend to be more precise, complete, and unambiguous [17]. Moreover, the resulting artefacts from the SRS process have to be understood by and be usable by domain experts and other stakeholders, such as analysts.

This paper contributes to the current RE community's body of knowledge on the empirical evaluation of efficiency and effectiveness of SRS techniques.

It presents the results of a mapping study which identified and categorized a set of primary studies that identify all quality aspects of the requirements specification process and product that are currently being considered by the researchers. Our categorization criteria include SRS aspect studied, type of empirical study, study setting, object of study, and problem domain. This mapping study emerged from our recent efforts in deploying the evidence-based paradigm [1] for the evaluation and interpretation of all available research relevant to a particular research field. The mapping study addresses the following research questions (RQs): *1) Which are the most investigated quality aspects of the SRS techniques? 2,3) In what study settings and in what problem domains are these aspects investigated? 4) What research method was used in the evaluation of the aspects studied? and 5) Which type of specification language is most studied by practitioners?*

In the following section we describe our review process. Section 3 discusses the results, Section 4 addresses the limitations of the mapping study, and Section 5 concludes the paper.

2. The mapping study approach

Research methodologists [7] define a mapping study as the "search of the literature to determine what sorts of studies addressing the systematic review question have been carried out, where they are published, in what databases they have been indexed, what sorts of outcomes they have assessed, and in which

populations". Such study is aimed at identifying and categorising research in a fairly broad topic area [11].

Our mapping study effort is informed by the systematic review processes established by [8][9]. However, this study is only the first step in a larger systematic review (SR) process, and as such, it does not aim to deliver results from an aggregation/ meta-analysis. Completion of the full SR is an objective of further research; however, the results of the mapping study are in themselves worth reporting. As shown in this paper, our mapping study revealed the most commonly investigated aspects of SRSs and the aspects that require more empirical research. We will see what implications these findings have for future research.

We carried out our mapping study in three stages:

i) developing a protocol that includes the definition of a search strategy and identification of inclusion/exclusion criteria;

(ii) selecting the relevant primary studies, and

(iii) classification of these studies selected. We used RQs for determining the scope, content, and structure of the mapping study as well as the procedural steps included in the three stages. The scope of the study is shown in Table 1.

Table 1. Scope based on the research questions

Population	Set of articles describing empirical studies in industry, academia and government reporting empirical evaluations.
Intervention	Any empirical study involving SRS, specification languages, methods, techniques and tools.
Outcomes	Quantity and type of evidence relating the evaluation of requirements specification.
Study design	Experiment, case study, experience reports, action research, observational study, and survey.

2.1. Search strategy

The search strategy comprises the search terms and the selected electronic database to be used, which are presented below.

With respect to ***search terms,*** we used a search string consisting of two parts. The first part will be related to the type of studies that we wish to include in the SR, such as: (1) experiment, (2) action research (3) experience report, (4) experimental study, (4) experimental comparison, (6) experimental analysis, (7) experimental evidence, and (8) empirical study.

The second part will be related to the specific technology to be reviewed, such as the following terms: (9) requirements specification technique, (10) requirements specification method, (11) requirements specification approach, (12) requirements modeling (US) (13) requirements modelling (UK), (14) requirements model, (15) requirements specification, (16) specification language, (17) modelling language and (18) requirements specification process.

Each term was chosen because we believe it describes the subject matter of the mapping study, namely the empirical evaluation of aspects of SRS processes and products. The 18 search terms are the result of a learning process, that is, we experimented with a variety of combinations of these words in order to test synonyms used in the literature. We considered it important to proceed in this way because no standardized, consistent terminology exists with respect to the topic of our study. We concatenated these terms, using boolean operators, in the following research string:

(1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8) AND (9 OR 10 OR 11 OR 12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18).

With respect to ***search resource***, we considered using mainly Scopus as the database for our review. .Scopus is the largest abstract and citation database of research literature. We preferred it because authors [9] of previously published reviews used it and found it has fewer weaknesses than other bibliographic databases. Although the majority of articles published in the IEEE Digital Library, Springer Library, and ACM Digital Library are included in Scopus, other complementary search resources were used since Scopus only includes in a partial form the articles of some conferences that are relevant to our research (please see Table 2).

Table 2. Search Resources availability

Proceedings	**Available in SCOPUS**	**Complementary Search resource**
ISESE : 2002-2006	2004-2005	ACM Digital library 2002-2003
CERE: 2003 - 2007	2006-2007	Manual search 2003-2005
RE: 1993-2008	1994-2007	IEEExplore 1993; 2008
ICSE: 1975-2008	1980-2008	ACM Digital library 1976-1979
REFSQ: 1994-2008	2008-2007	Manual search 1994-2006
WER: 1998-2008	--	Manual search
AWRE: 1999-2005	--	Manual search

Thus, we also used the ACM Digital Library and IEEExplore, and did a manual search in the following electronic volumes of for conference/workshop proceedings: Requirements Engineering – Foundation of Software Quality (REFSQ), Workshop on Requirements Engineering (WER), Australian

Workshop in Requirements Engineering (AWRE), and Comparative Evaluation in Requirements Engineering (CERE).

2.2. Study selection criteria

The study selection criteria are governed both by the inclusion and exclusion criteria and study selection process, which are described below.

2.2.1. Inclusion/Exclusion Criteria. To select papers from the retrieved results, our protocol used the following ***inclusion criteria***:

I1: The paper empirically evaluates one or more requirements specification approaches either in industrial or academic or government settings;

I2: The paper empirically compares two or more requirements specification approaches.

I3: In the case of dissimilar and similar replications, each one of them was considered.

The protocol also considered these ***exclusion criteria***:

E1: The paper theoretically evaluates one or more features of an SRS technique (e.g. expressive power, semantic equivalence).

E2: The paper presents an approach to the theoretical evaluation of SRS technique (e.g. model-checking).

E3: Empirical studies on the evaluation of such approaches are also excluded;

E4: Empirical studies that evaluate software artifacts produced in analysis, design and implementation phases;

E5: If two papers publish the same empirical results, one of them is excluded;

E6: Any paper that is not accessible is excluded;

E7: We excluded editorials, prefaces, posters, summaries of articles, and tutorials, workshops, and panels.

2.2.2. Study Selection Process. We treated the selection of studies as a pre-review process in which a particular paper is screened and judged based on the inclusion and exclusion criteria. This process comprises four iterations, as shown in Figure 1. Only papers which met these requirements were used for the analysis in the categorization stage. The selection process classified 34 out of the 206 papers from SCOPUS for inclusion. We also deemed relevant for inclusion 4 of 29 papers from ACM digital library, 2 papers from WER, and 6 papers from REFSQ.

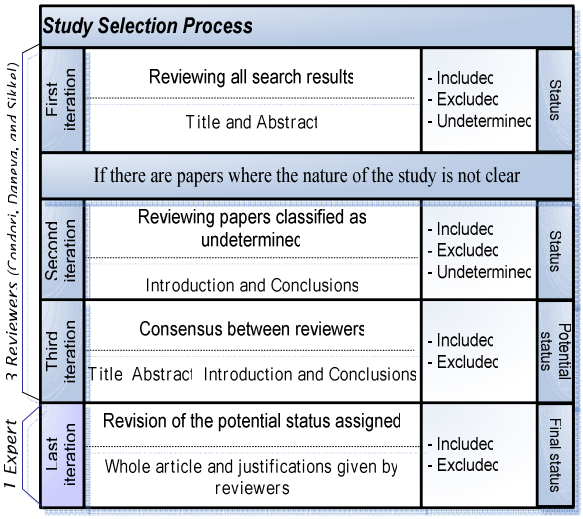

Figure 1. Study selection process

Next, the exclusion criteria most often used in the selection process are illustrated.

- Attiogbé [18] analysed formal specifications produced with the Atelier-B tool, using Model Checking to discover errors and therefore to improve the former specifications. Applying the E1 criteria, this paper was not included.
- Bernárdez et al [19] carried out an empirical evaluation of a metrics-based approach for use case verification. Applying the E3 criteria, this paper was not included.
- Briand et al [20] realized an empirical evaluation of the maintainability of object-oriented and structured design documents. Applying the E4 criteria, this paper was not included.

Table 3 shows the top five publication channels. The MODELS, REFSQ and ICSE conferences seem to be the dominant forums as 13% of 46 papers selected are published there.Davis et al [3] observed that the relative size of the Requirements Engineering Journal has decreased slightly; we confirmed it since that very few papers on evaluation of SRS approaches were published there.

Table 3. Top five publication channels (1987-2008)

Acronym	Type of publication	Percent
MODELS	Conference	13.0%
ICSE	Conference	13.0%
REFSQ	Conference	13.0%
ISESE-ESEM	Conference	8.7%
RE	Conference	6.5%

3. Results Analysis: Categorization

According to our protocol, we categorized our results according to the following criteria:

- *Type of empirical study*: To facilitate the correct identification of type of empirical study, we opted for use of three factors proposed by Tonella et al [13]: Multiplicity (whether several cases are observed); Control (whether control has been exercised on the main factor and on the context factors and cofactors) and Randomness (whether the assignment to the groups was random or for convenience). The combination of these factors, six types of empirical study were considered: *experience report, case study, experiment, observational study, action research and survey*.

  If only one or a few cases are observed, we have, depending on the level of control applied, one of two types of studies: *Experience report*: the treatment is applied to one case, but no specific effort is devoted to controlling the context [12]. Accordingly, the set-up, data collection, and data analysis are not discussed in detail. *Case study*: the treatment is applied to one case, and the collection of data, targeting insight in the attributes of a set of products or processes, is discussed in detail, as are the set-up and data analysis. No variables are manipulated at different levels.

  When multiple cases are observed, we can distinguish whether or not control is applied and then, whether or not randomness is sought. *Experiment*: the treatment is applied under control in order to observe the effects. *Observational study*: a study that unobtrusively gathers observations in search for statistical support connecting factor and effect variables. Such a study often takes the form of a *Survey*, in which random sampling is applied to select a population of cases to be observed. Finally, *Action research* focuses particularly on combining theory and practice [21]. It attempts to provide practical value to the client organization while simultaneously contributing to the acquisition of new theoretical knowledge.

- *Study setting:* this refers to the context in which studies are realized. It can be in *industry, government or academic* settings. We considered also the combination of these as a mixed setting. For example, experiments carried out with real life problems from industry and with subjects from academia.

- *Object of study:* this refers to the object being analyzed in the empirical studies. This can be *language; method, technique*[1] *(guidelines, diagrams, etc.), tool and SRS*. An empirical study of a SRS method typically can include more than one SRS language (*Multilanguage*). Similarly, an empirical study of a SRS tool is focused on a particular tool used in support of an SRS process/method. Unfortunately, in most cases, it is hard to separate the language from the method, or the method from the tool. Moreover, when a comparative study is conducted, there may be more than one object of the study. In this paper, categorization was only realized with respect to the type of specification language (formal, semiformal, natural language). This was due to the difficulties that we had in correctly identifying objects of study since this issue in primary studies was not clearly described.

- *Aspect studied:* this refers to quality properties being investigated in an empirical study (e.g. completeness, reusability, understandability). One object of study can be evaluated by using one or more quality properties. Although there are few quality models for evaluating different objects of study that are produced in the RE discipline, we carried out a process of similar terminology unification. For example, the level of granularity and level of abstraction were unified by the second term.

- *Domain:* we cannot evaluate an SRS technique without discussing where its use could be appropriate. Although there is no consensus for taxonomy of domains, we consider the following types proposed by Kotonya [10]: *command and control, embedded software, electronic commerce, real-time (e.g. sensors), management information systems, simulation, and virtual reality.*

As we can see in Figure 2, each criterion itself or each relationship between them represents one potential RQ. We prioritized the analysis of the aspect studied by the researchers and its respective relationships. We identified five RQs which are analysed and discussed below.

[1] We define technique as a recipe for obtaining a certain result. It can be said that methods contain techniques to perform particular tasks, and that techniques prescribe a way of working in detail [2].

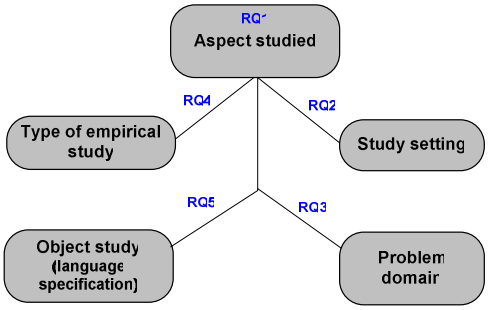

Figure 2. Criteria and research questions

1) Which are the most investigated aspects of SRS techniques?

We selected 31 aspects studied for our research. Table 4 reports the number of occurrences of these aspects in the primary studies. It indicates that the top-five most studied aspects are: understandability, efficiency, correctness, defect rate, and completeness. We found 11 aspects with only one occurrence. This might be indicative that more research is needed to understand these aspects of SRS approaches (for example, appropriateness, intention to use, ease of analysis, perceived ease of use, etc.).

Table 4. SRS aspects investigated

Aspect studied	Frequency	Percent
Understandability	19	41.3%
Efficiency	9	19.6%
Correctness	6	13.0%
Defect rate	5	10.9%
Completeness	5	10.9%
Consistency	4	8.7%
Readability	3	6.5%
Usefulness	3	6.5%
Ease of learning	3	6.5%
Traceable	3	6.5%
Acceptability	2	4.3%
Usability	2	4.3%
Testability/simulation	2	4.3%
Level of Abstraction	2	4.3%
Communication	2	4.3%
Plausibility	2	4.3%
Consistency of structure	2	4.3%
Alternative flow	2	4.3%
Misinterpretation	2	4.3%
Ease of Construction	2	4.3%
Cost Effectiveness	1	2.2%
Checkability	1	2.2%
Soundness	1	2.2%
Verifiability	1	2.2%
Perceived ease of use	1	2.2%
Intention to use	1	2.2%
Precision	1	2.2%
Appropriateness	1	2.2%
Ease of use	1	2.2%
Ease of analyze	1	2.2%
Reuse	1	2.2%

2) In what study settings are these aspects investigated?

Table 5 indicates that almost 58.7% of the studies took place in an academic environment. Clearly, empirical studies in government settings are rarely undertaken.

Table 5 Distribution of study setting

Study setting	Frequency	Percent
Academic	27	58.7 %
Mixed	10	21.7 %
Industrial	8	17.4 %
Government	1	2.2 %
Total	46	100.0 %

We mapped the 31 aspects being studied against the categories of settings. Table 6 presents the mapping result for the top five aspects listed in Table 4. Table 6 shows that 84.2% of the studies on understandability are carried out in an academic context. Only 10.5% are done in an industry setting. We also note that 40% of the studies on the defect rate aspect are investigated in a mixed context (i.e. subjects from academia and industry). In addition, the completeness aspect is exclusively investigated in academic settings. However, none of the studies on the top five aspects is investigated in a government setting. This might be a preliminary indication that our knowledge of these aspects has been accumulated one-sidedly and was shaped, by and large, by what university researchers believe it is important to evaluate. This might or might not be what practitioners perceive as important. In any case, we believe the results in Table 6 indicate the need for more empirical research on these SRS aspects.

Table 6. Aspects studied-types of settings

Aspects	Academic	Industrial	Mixed	Government
Understandability	84.2%	10.5%	5.3%	0%
Efficiency	44.4%	22.2%	33.3%	0%
Correctness	83.3%	0.0%	16.7%	0%

Aspects	Academic	Industrial	Mixed	Government
Defect rate	40.0%	20.0%	40.0%	0%
Completeness	100.%	0.0%	0.0%	0%

3) In what problem domains are these aspects investigated?

Table 7 shows that the dominant applications are Management Information Systems (MIS). However, this result is not significant since a large proportion of primary studies do not indicate the type of application used.

Table 7. Aspect studied – Type of application

	Command & Control	E-Commerce	Embedded software	MIS	Real-time	Virtual reality	Not indicated
Understand-ability	5.3 %	5.3 %	5.3 %	31.6 %	5.3 %	.0%	47.4 %
Efficiency	.0%	.0%	.0%	66.7 %	11.1 %	11.1 %	11.1 %
Correctness	.0%	16.7 %	16.7 %	33.3 %	.0%	.0%	33.3 %
Defect rate	.0%	.0%	.0%	40.0 %	.0%	.0%	60.0 %
Complete-ness	.0%	20.0 %	.0%	40.0 %	.0%	.0%	40.0 %

4) What research method was used in the evaluation of the aspect studied?

Table 8 provides the answer to this question. It suggests that experiments are by far the most used research approach. 63% papers relied on experiments. Our mapping study indicated 13% papers only which used case study research, despite the fact that the RE community agrees on the importance and the benefits of case study research in RE investigating RE phenomena.

Table 8. Distribution of empirical research

Empirical research	Frequency	Percent
Experiment	29	63.0 %
Case Study	6	13.0 %
Observational Study	4	8.7 %
Experience report	4	8.7 %
Pilot Study	2	4.3 %
Survey	1	2.2 %
Total	46	100.0 %

Table 9 reports on the research methods being used in studies of the top five investigated aspects.

Table 9. Aspects by type of empirical research

Aspects	Case Study	Experience report	Experiment	Observational Study	Pilot Study	Survey
Understand-ability	10.5 %	0.0 %	68.4 %	5.3 %	10.5 %	5.3 %
Efficiency	11.1 %	22.2 %	55.6 %	0.0 %	11.1 %	0.0 %
Correctness	16.7 %	0.0 %	83.3 %	0.0 %	0.0 %	0.0 %
Defect Rate	20.0 %	0.0 %	60.0 %	20.0 %	0.0 %	0.0 %
Complete-ness	0.0 %	0.0 %	100. 0%	0.0 %	0.0 %	0.0 %

5) Which is the SRS language most studied by the practitioners?

Semi-formal SRS languages accounted for 54.3% of the studies. We found UML and i* to be predominant. We can see in Table 10 that there has been more investigation of formal languages with respect to the efficiency aspect (effort used to specify, productivity, etc). However, correctness has only been investigated by practitioners using semi-formal languages. We also see 36.8% of the studies on understandability were carried out in two or more different specification languages (formal, semi-formal, or informal) since comparative evaluations were performed. In this mapping study we do not explore in detail the type of specification language involved for a Multilanguage category. Note that empirical evaluations of informal language were not found.

Table 10. Aspects by type of language specification

Aspects	Formal	Multilan-guage	Semi-formal
Understandability	5.3%	36.8%	57.9%
Efficiency	44.4%	0.0%	55.6%
Correctness	0.0%	0.0%	100.0%
Defect rate	0.0%	20.0%	80.0%
Completeness	0.0%	0.0%	100.0%

4. Limitations of this study

The main limitations of the mapping study are: (i) bias in the selection of publications to be included, and (ii) categorization.

To help to ensure that the process of *selection was unbiased*, we developed a review protocol, by defining our search strategy and study selection process. We

note here that our access to 'relevant' sources depended on the appropriateness of the search strings used. The diversity of terms used in the empirical software engineering means that we may have missed some relevant studies. To diminish this limitation, we treated the composition of the search string as a learning process [14]; the list of search strings was adapted six times and the search was re-run with the new terms. Therefore, there is a need to develop ontologies for describing the findings of these empirical studies [15]. In addition, the exclusion of papers written in a language other than English leads to biased estimates of the effectiveness of the selection process. We could not avoid this limitation since English was the only feasible common language to be used by the revision team.

Another limitation arises from the question whether our *categorizations* are robust enough for analysis. This is a validity threat common to mapping studies. In our research, we used five classification criteria: aspects studied of SRS approaches, type of empirical evaluation used, type of study setting where empirical studies are carried out, type of specification language and domain problem. In our experience, the best way to classify the primary studies can only be known when the papers are known themselves and there is at least a minimum supervision by an expert. We had difficulties mainly with correct identification of the following:

1) The type of empirical study, e.g. what exactly is deemed a case study; according to [12] this is very rarely used as an evaluation method. However, most of the papers when they refer to 'case study' in fact mean 'proof of concept'.

2) Aspect studied; as everyone has their own interpretation of what quality term to use, we carried out a prior process of terminology unification.

3) Problem domain; it was not possible to obtain an exhaustive list of all possible domains where business users may decide to put software systems. However, a list of applications types was considered [10].

5. Summary and implications

This mapping study reported on the SRS aspects being investigated in the RE literature, the settings in which the evaluation of SRS took place, and the research methods being used for such evaluation. We found 31 aspects of SRS which were studied. A key question is which of these aspects need further study. Clearly, aspects such as understandability are important, but which aspects are actually problematic in the real world? Our position is that problematic aspects need to be studied first. It might be the case that understandability or efficiency is studied so often because it is easier to study in an experimental context, and not because it is the most important problem in the real world. Understanding whether this is so would be worthwhile investigating in future research.

Furthermore, our mapping study revealed very few real-world case studies are published. More technical action research (researchers using their own techniques in a real-world project) will be necessary in order to understand the problematic aspects of using SRS techniques in specific contexts, where stakeholders have different roles and needs that would impact on any empirical evaluation.

We found that a majority of academic work so far has focussed strongly on experiments, and where the generalisability of results may be compromised as a result. This clearly indicates the need for more research to evaluate SRS techniques in real-life settings.

As a next step we aim to exhaustively assess study quality focussing on understandability, efficiency, and correctness of SRS in order to integrate various qualified primary studies within a systematic review process.

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